METU JFA 2009/2
(26:2) *69-89*

DOI: 10.4305/METU.JFA.2009.2.4

SPACE EFFICIENCY IN HIGH-RISE OFFICE BUILDINGS

Ayşin SEV and Aydan ÖZGEN

Received: 19.11.2008, **Final Text:** 30.07.2009

Keywords: high-rise office building; space efficiency; floor slab; gross floor area; net floor area; structural system, core configuration.

1. The authors would like to thank all those who provided data to make this research possible.

INTRODUCTION

High-rise office buildings (**1**), which are developed as a response to population growth, rapid urbanization and economic cycles, are indispensable for a metropolitan city development. In 1930, Clark and Kingston (cited in Klaber, 1930) made the following observations *The skyscraper: A study in the economic height of modern office buildings:*

> "Given the high land values in central business sections of our leading cities, the skyscraper is not only the most efficient, but the only economic utilization of certain strategic plots. An exhaustive investigation… has conclusively demonstrated that the factors making for diminishing returns in the intensive development of such plots are more than offset by the factors making for increasing returns…" (Klaber, 1930).

This statement holds true for today; however, the relationship between cost and benefit is more complex in today's global marketplace. The political ideology of the city plays an important role in the globalization process (Newman and Tornely, 2005; Abu-Ghazalah, 2007). The current trend for constructing office buildings is to build higher and higher, and developers tend to compete with one another on heights. Tenants also appreciate a landmark address and politicians are conscious of the symbolic role of high-rise buildings. The international and high technology styles have accompanied nearly all new tall buildings and became landmark of our cities (McNeill and Tewdwr-Jones, 2003). Nonetheless high-rise office buildings are more expensive to construct per square meter, they produce less usable space and their operation costs are more expensive than conventional office buildings. The space efficiency, as well as the shape and geometry of the high-rise building need to satisfy the value and cost of the development equation. Space efficiency, which is determined by the size of the floor slab, dimension of the structural elements and rationalized core, goes along with the financial benefit.

By the end of 1990s, at more than 30 stories, net to gross floor area ratios of 70-75% were common in office buildings (**Table 2**) (Davis Langdon and Everest, 1997). However, Yeang (1995) stated in his book "*The Skyscraper: Bioclimatically Considered*" that net-to-gross floor area should not be less than 75%, while 80% to 85% is considered appropriate. Wherever the tall building is being constructed, achieving suitable space efficiency is not easy, since it is adversely affected by height as core and structural elements expand to satisfy the requirements of vertical circulation and resistance to lateral loads. Space efficiency can be increased by the lease span, which is defined as the distance between the core and exterior wall.

Factors affecting the design of high-rise buildings vary from country to country, such as local climate, zoning regulations, cultural conditions, technological opportunities, and etc. For instance, in Germany, where building codes dictate shallow floor slabs of 8.0 m, efficiencies of 60-70% are common, whereas London's Canary Wharf Tower, can achieve a net-to-gross ratio in excess of 80% with floor slabs of 2500 m^2, and 11.0 m lease span. In this respect, when the high-rise office buildings of Turkey are investigated, conceivable space efficiency is not achieved when compared with the examples from the world. As Watts and et al. (2007) stated in their article that "fat is happy", the highest office buildings of Turkey are happy, however, they are not so successful in respect to space efficiency. Therefore this research tends to compare and reveal the similarities and differences between the tallest office buildings at abroad and in Turkey in terms of space efficiency.

DESIGN CONSIDERATIONS FOR HIGH-RISE OFFICE BUILDINGS

The study is based on the ten tallest office buildings in the world and in Turkey individually, which are registered by Council on Tall Buildings and Urban Habitat (CTBUH, 2008) in November 2008 and also recorded in Emporis.com (2008) and SkyscraperPage.com (2008), as shown in **Table 1**. All of the sample buildings are landmarks of their cities, and also are designed by internationally expertise design consultants, reflecting high-quality practices in respect of efficient planning. The relevant building data are provided from the clients, architects, engineers, quantity surveyors, as well as journals, books, magazines and Internet sources. The research is based on the architectural and structural design criteria affecting the space efficiency, such as floor slab size and layout, core integrity, gross and net floor areas, leasing depth, floor-to-floor and floor-to-ceiling height, and structural system.

The sample buildings from the world are located in seven major cities, which are Taipei, Kuala Lumpur, Shanghai, Chicago, Hong Kong, Guangzhou and Shenzhen. The height ranges of these buildings are between 367 m and 509 m, and the numbers of stories change from 69 to 114. The Empire State Building in New York, which is currently the ninth tallest office building of the world, is omitted, since it is constructed 78 years ago. The paper tends to take contemporary examples into consideration due to the rapid changes in tall building design and construction technologies.

The list of the tallest buildings of Turkey in Emporis.com (2008) and SkyscraperPage.com (2008) comprise a large number of residential towers, of which have been omitted from the list mentioned in this paper. Nine of ten selected examples of office buildings are located in İstanbul, while

	Name of Building	City	Year of Completion	Height (m)	Number of Floors
WORLD	Taipei 101 Tower	Taipei	2004	509	101
	Shanghai World Financial Center	Shanghai	2008	492	101
	Petronas Tower 1-2	Kuala Lumpur	1998	452	88
	Sears Tower	Chicago	1974	442	110
	Jin Mao Tower	Shanghai	1998	421	88
	Two International Finance Center	Hong Kong	2003	415	88
	CITIC Plaza	Guangzhou	1997	391	80
	Shun Hing Square	Shenzhen	1996	384	69
	Central Plaza	Hong Kong	1992	374	78
	Bank of China	Hong Kong	1990	367	70
TURKEY	İşbank Tower 1	İstanbul	2000	181	52
	Mertim	Mersin	1992	175	49
	Tekstilkent Plaza 1-2	İstanbul	2006	168	44
	Sabancı Center 1	İstanbul	1993	158	39
	Süzer Plaza	İstanbul	1998	154	34
	Tat Tower 1-2	İstanbul	2000	143	34
	Metrocity Tower 1	İstanbul	2000	143	31
	Sabancı Center 2	İstanbul	1993	140	30
	Beybi Giz Plaza	İstanbul	1996	136	34
	Garanti Bank Headquarters	İstanbul	2002	122	22

Table 1. Ten tallest office buildings of the world and Turkey (adapted from CTBUH Skyscraper.com and Emporis.com in November 2008).

Number of Stories	Efficiency (%)
Two to four	83-86
Five to nine	79-83
10 to 19	72-80
20 to 29	70-78
30 to 39	69-75
40 +	68-73

Table 2. Building efficiency (net-to-gross floor area) of multi-story office developments (Davis Langdon and Everest, 1997).

the remaining example, Mertim, is located in Mersin. Mertim, originally designed as an office building, is currently utilized as a hotel. The heights of these buildings vary between 122 m and 181 m, while the number of storeys change between 22 to 52, as shown in **Table 1**.

Architectural and structural requirements are the basic decision making parameters in the design of high-rise office buildings, and dictate the floor slab size and shape, leasing depth, structural frame, floor-to-floor height, vertical transportation and core layout. The related findings of the selected buildings from the world and Turkey are presented and discussed below.

Floor Slab Size and Shape

An office building's floor slab size and shape, on which decisions are made according to the functional requirements, client's specific needs and various constraints, have great impact on the space efficiency and the building's external character. Although there are no universal formulas for responding to the client's needs or to local influences and constraints such as climate, codes or constructional conditions, the fundamental design considerations are identical almost in office buildings (Kohn and Katz, 2002; Strelitz, 2005). The first aim is to achieve the maximum space efficiency and in order to accomplish this task, initially the floor slab shape and total floor area of the building need to be designed.

The space efficiency of a high-rise office building can be achieved by maximizing the Gross Floor Area (GFA) and Net (usable) Floor Area (NFA) as permitted on the local site by the codes and regulations, and in order to enable the developer and owner to get maximum returns from the high cost of land, the floors must have sufficient functional space (Kim and Elnimeiri, 2004). In the initial stages of the design, the designer ascertains the extent of GFA and NFA in the proposed concept design, and these figures are used as the bases for core configuration and structural system. By the final decision, the NFA is sealed with the exact core area and the vertical structural elements. Net-to-gross floor area of a typical floor slab is of crucial economic interest to the developer, since it designates the space efficiency of the floors, at the same time as the more efficient the typical floor slab is, the more usable area the developer gets and the more income is derived from the building.

According to Yeang (1995; 2000), floor slab efficiency of a typical high-rise office building should generally not be less than 75%, unless the site is too small or too irregular to permit a higher level of space efficiency. Floor slab designs using clever devices, such as scissor stairs, pressurized lift shafts, dispersal of toilets etc. can increase efficiency up to 80% - 85 % per typical floor. However, as Watts et al. (2007) state in their recent article, floor slab efficiency is adversely affected by the height of a high-rise office building, as the core and structural elements expand relatively to the overall floor slab to satisfy the requirements of vertical circulation as well as lateral-load resistance. Tall buildings with high slenderness ratio are inherently more expensive to build and suffer from adverse floor slab efficiency.

Although space efficiency is simply defined as the ratio of NFA to GFA, the matter is more complicated in terms of its effects. The floor slab shape also has a vital importance as well, since it influences the interior space planning, layout of office equipments, exterior building envelope, structural system and component sizes, utilizing from natural light and air, access to escape routes, etc. Generally the more simple and regular the floor slab shape is, the easier it is to respond to user requirements in terms of space planning and furnishing. Square, circular, hexagonal, octagonal and similar plan forms are more space efficient than the rectangular plans with high aspect ratios and irregular shapes. Buildings with symmetrical plan shapes are also less susceptible to wind and seismic loads (Arnold, 1980; Taranath, 1998; Kozak, 1991).

The site areas of the selected examples from the world and Turkey are large due to their prestigious status, so the floor slab areas are not constrained by the maximum site coverage. The floor slab areas of buildings abroad are comparatively large due to their sheer heights, and range from 2150 m^2 to 4900 m^2 in typical floors, whereas the buildings from Turkey have typical floor slab areas ranging from 700 m^2 to 1406 m^2 (**Table 3**). The space efficiency of the buildings at abroad change from 60% to 77% , and the Sears Tower achieves maximum efficiency with the value of 77% , where as the Petronas Towers are least space efficient in typical floors. The office towers in Turkey have space efficiency ranging between 61% and 78% with the lowest efficiency in İşbank Tower 1 and highest efficiency in Tekstilkent Plaza 1 and 2. Garanti Bank Headquarters is a remarkable example having a high space efficiency of 77%, however, this building has multiple interior columns dispersed throughout the workspace, and these columns significantly prevent the flexibility of the usable area. The least

	Name of Building	GFA (m²)	NFA (m²)	Space Efficiency (%)	Interior Columns	
					Single	Multiple
WORLD	Taipei 101 Tower	2650	1920	72	No	
	Shanghai WFC	2500	1750	70	No	
	Petronas T. 1-2	2150	1290	60	No	
	Sears Tower	4900	3780	77	Yes	
	Jin Mao Tower	2800	1940	69	No	
	Two International Finance Center	2800	1904	68		Yes*
	CITIC Plaza	2230	1500	67	No	
	Shun Hing Square	2160	1450	67	No	
	Central Plaza	2210	1460	66	Yes	
	Bank of China	2704	1865	69	No	
	Average			**68.5**		
TURKEY	İşbank Tower 1	1400	860	61	No	
	Mertim	1260	920	74	No	
	Tekstilkent P. 1-2	1406	1100	78	Yes	
	Sabancı Center 1	700	460	66		Yes*
	Süzer Plaza	1400	1000	71		Yes*
	Tat Tower 1-2	990	652	66	No	
	Metrocity Tower 1	830	558	67		Yes*
	Sabancı Center 2	725	460	63		Yes*
	Beybi Giz Plaza	810	590	72	Yes	
	Garanti Bank Headquarters	1500	1160	77		Yes
	Average			**69.5**		

Table 3. GFA, NFA and space efficiency of the ten tallest office buildings of the world and Turkey (Sev, 2000).

* These buildings have peripheral columns recessed from the exterior wall.

space efficient example, the İş Bank Tower, has a relatively large core area; thus significantly decreasing the usable floor area.

The mean average value of space efficiency of the ten tallest buildings of the world is 68.5 %, whereas the mean average in Turkey is 69.5 %. Although there is a significant distinction between the number of floors and heights of the examples at abroad and in Turkey, it is observed from the analysis that the space efficiencies are very similar in terms of net-to-gross floor areas.

As shown in **Figure 1a** and **Figure 1b**, square or similar plan geometries are the most preferred shapes in examples at abroad. Seven of the ten tallest buildings at abroad have plan geometries derived from square. Since this geometry offers the same stiffness in each direction against lateral loads, square or similar configurations are the most common in the selected examples. Petronas Towers are deemed acceptable, since they have symmetrical and regular plan forms, enabling similar planning and structural efficiency in each direction. The Central Plaza, with its triangular plan form can be regarded as regular, since it enables equal leasing depth in each perimeter, however, it is not susceptible to lateral loads in each direction, and the only column in the usable area prevents the flexibility of space. Shun Hing Square with its hybrid plan shape is the only example of irregular configurations, thus disabling equal leasing depths in each perimeter of the tower; and the workplace is separated into four regions.

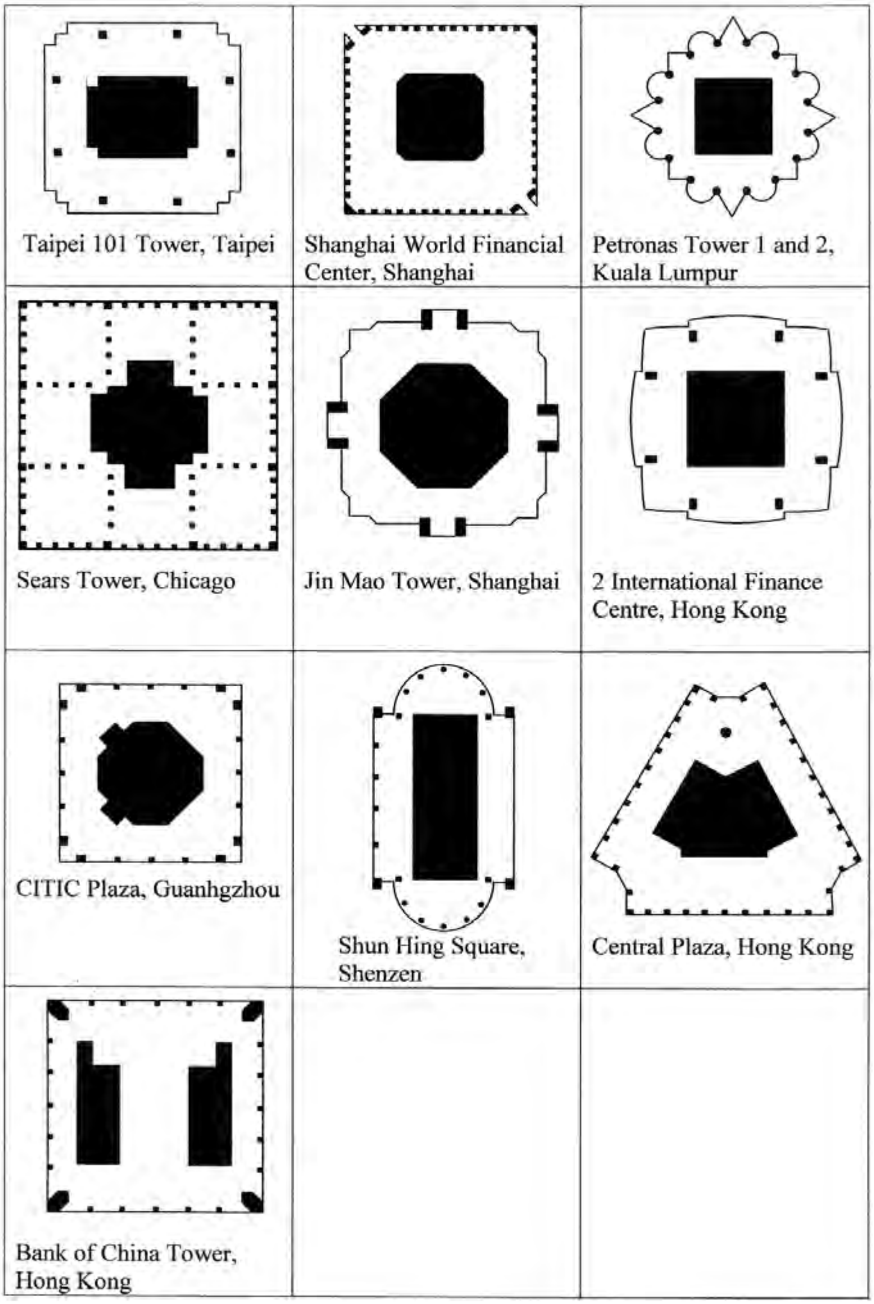

Figure 1a. Geometry of typical floor plans of ten tallest office buildings of the world.

The selected office buildings from Turkey have different characteristics of plan geometry when compared with the ten tallest office buildings of the world. Only one case, İşbank Tower has a plan shape derived from square, however, the core geometry do not match with the plan layout, thus disabling equal space efficiencies in each perimeter. Mertim and Süzer Plaza have rectangular plan forms with matching core geometries, and though they are not symmetrical in each direction, the plan configuration enables equal and efficient work spaces in each perimeter. Sabancı Towers, Metrocity 1, Beybi Giz Plaza and Garanti Bank Headquarters are the examples of hybrid and unsymmetrical plans, whereas the Tat Towers and Tekstilkent Plaza 1 and 2 are composed of hexagonal form and similar core configuration.

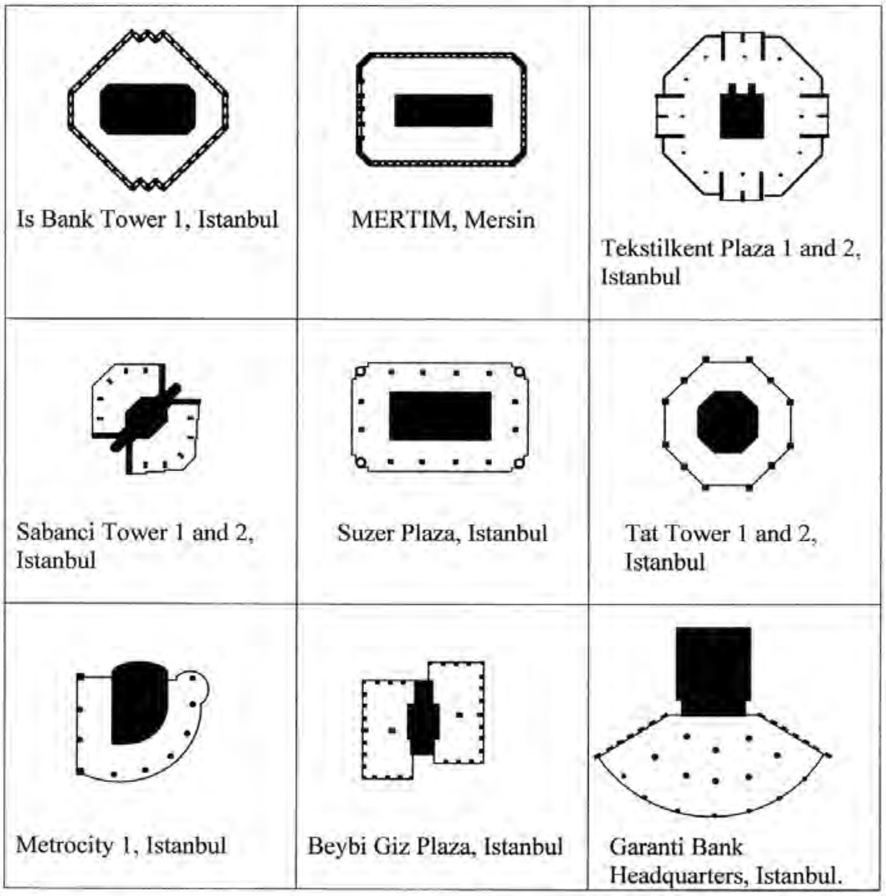

Figure 1b. Geometry of typical floor plans of ten tallest office buildings in Turkey.

There is a conspicuous intend that the contemporary office buildings must be designed with minimum or no interior columns to enable maximum flexibility, consequently a column-free floor slab from the exterior to the core is the optimum solution for the office development. However, as shown in Figure 1a, the analyzed buildings at abroad, except for the Sears Tower and the Central Plaza, are column free in the leasing depth. Three of the sample buildings from Turkey, Tekstilkent Plazas, Beybi Giz Plaza and Garanti Bank Headquarters, have interior columns, as Sabancı Center 1 and 2, Süzer Plaza and Metrocity 1 have peripheral columns recessed from the exterior wall. The least sufficient workplace can be observed in the typical floor plans of Garanti Bank Headquarters with multiple columns dispersed throughout the floor slab (Figure 1b). Although this building has a workplace organized into one space, the interior columns prevent the flexibility and efficiency of this usable space, presenting the disadvantage of a non-column-free floor slab as stated above.

Leasing Depth

Leasing depth or lease span is the distance of the usable area between the exterior wall and the fixed interior element, such as the core or the multi-tenant corridor. Although it depends on the functional requirements and is closely related with the structural frame and the material, there are considerable varieties in different markets. For example, in Germany maximum leasing depth is determined by building codes and cannot be more than 8.0 m, whereas in Japan it is typically 18.0 m (Kohn and Katz, 2002). In the United States, floor slab areas began to expand after the World

War II with the help of technological innovations, such as air-conditioning and artificial lighting. Today there are high-rise office buildings with 17.0 m lease span in United States and Asia.

Smaller core-to-exterior window dimensions allow the users to maintain a relationship with the outside, thus benefiting from the natural light. According to Ali and Armstrong (1995) the depth of lease span must be between 10.0 and 14.0 m for office functions, except where very large single tenant groups are to be accommodated. Maximum leasing depth has remained relatively static over the last 30 years as it is recognized that the maximum income for office development is achieved when a high percentage of the workers are located within an 8.0 m zone of the perimeter wall. Corner offices and the articulation of the façade significantly improve the ability to provide more space efficiency and quality than spaces with greater leasing depth. As floors become deeper, the marketability of the space significantly decreases (Crone, 1990).

From the collected data in **Table 4**, the leasing depths in ten tallest office buildings of the world change between 8.3 m and 22.9 m. with an average depth of 12.1 m. Structural floor materials of the examples at abroad are composite, except for the Central Plaza, which utilizes a reinforced concrete floor frame.

The average leasing depth in Turkey's tallest office buildings is 10.2 m, having a range between 7.75 m and 14.8 m. The Garanti Bank Headquarters with a leasing depth of 27.0 m is not included in the average, since there are multiple interior columns in the workplace (**Figure 1b**). In Turkey, all of

Table 4. Leasing depth, floor-to-floor and floor-to-ceiling heights of sample buildings from the world and Turkey (Sev, 2000).

	Name of Building	Leasing Depth (m)	Floor-to-floor height (m)	Floor-to-ceiling height (m)	Structural floor material
WORLD	Taipei 101 T.	13.9 – 9.8	4.20	2.80	Composite
	Shanghai WFC	12.5	4.20	2.75	Composite
	Petronas T. 1-2	13.0 – 8.3	4.00	2.65	Composite
	Sears Tower	22.9	3.92	2.70	Composite
	Jin Mao Tower	14.8 – 11.8	4.00	2.79	Composite
	Two International Finance Center	14.5	4.00	2.70	Composite
	CITIC Plaza	11.3	3.90	2.70	Composite
	Shun Hing Square	12.5 – 12.0	3.75	2.65	Composite
	Central Plaza	13.5 – 9.4	3.90	2.60	Reinforced concrete
	Bank of China	17.6	4.0	2.80	Composite
	Average	**12.1**	**3.98**	**2.7**	
TURKEY	İşbank Tower 1	14.8 – 9.1	3.70	2.70	Reinforced concrete
	Mertim	10.0 – 8.5	3.40	2.60	Reinforced concrete
	Tekstilkent P.1-2	11.5	3.80	2.65	Reinforced concrete
	Sabancı C. 1	10.75	3.50	2.80	Reinforced concrete
	Süzer Plaza	7.75	3.60	2.75	Reinforced concrete
	Tat Tower 1-2	8.8	3.87	2.80	Reinforced concrete
	Metrocity T. 1	9.0	3.50	2.70	Reinforced concrete
	Sabancı C. 2	10.75	3.50	2.80	Reinforced concrete
	Beybi Giz Plaza	11.5	3.40	2.75	Reinforced concrete
	Garanti Bank Headquarters	27.0	4.08	2.80	Reinforced concrete
	Average	**10.2**	**3.6**	**2.7**	

the sample buildings without exception, utilize reinforced concrete as the structural floor material.

Floor-to-floor / Floor-to-ceiling Height

The floor-to-floor height of an office building is typically the same for all occupied floors except for the lobby and floors for special functions. In high-rise office buildings, additional floor-to-floor height significantly entails greater cost on structural elements, cladding, mechanical risers, and vertical transportation.

The floor-to-floor height of a building is a function of the required ceiling height, the depth of the raised floor (if used), the depth of the structural floor system and material (which is dependent on the exterior-to-core distance), and the depth of the space required for mechanical distribution. Baum (1994), in his book "*Quality and Property Performance*", defines quality in office buildings and suggests that the plan layout and the ceiling height are more significant than the following three determinants of building quality: (i) Services and finishes; (ii) external appearance and (iii) durability of materials.

Another research project by Ho (1999) reveals that functionality of the floor slab is the most important category indicated by all the respondents of the investigation, except for users, who emphasized services as the relative importance of functionality. Designers in the same investigation rated functionality as their most important determinant of quality, because they usually start the design process by working around constraints such as plan shape, usable floor area, and floor-to-floor heights.

Commercial functions require a variety of floor-to-ceiling heights ranging between 2.7 and 3.7 m (Ali and Armstrong, 1995), and the depth of the structural floor system varies depending on the floor loads, size of structural bay, and type of floor framing system. In the case of steel floor framing, an allowance for fire-proofing must be made. However, in steel systems, increasing the structural depth will result in decreased weights of rolled sections. Trusses, which permit the passage of ducts, provide structural depth without increase in floor-to-floor height.

According to the analyzed buildings of the world, the floor-to-floor heights change between 3.73 m and 4.20 m with an average of 3.98 m (**Table 4**). The floor-to-ceiling heights have a range changing between 2.65 m and 2.8 m with an average of 2.7 m. Raised floor is provided in Taipei 101 Tower, Sears Tower, Petronas Tower 1 and 2, and Two International Finance Centre. The tallest office buildings in Turkey have floor-to-floor heights changing between 3.40 m and 4.8 m with an average of 3.6 m, which is under the average of the examples at abroad. The floor-to-ceiling heights also have a range between 2.60 m and 2.80 m, with an average of 2.7, thus being close to the average value of the ten tallest office buildings of the world.

Core Integrity

The core of the building comprises all of the vertical circulation elements, such as elevators, fire-stairs, mechanical shafts, toilets, and elevator lobbies. In early office buildings, these elements tended to be dispersed on the floor rather than concentrated, while today's contemporary buildings include all these elements in a specific zone, which is mainly the core. Many of the key structural elements, such as the shear walls that provide lateral stability, are integrated into the core in order to simplify the architectural design.

Layout of the core is critical to the development efficiency and operational effectiveness of a high-rise office building, while also playing a significant role in the way the structure copes with lateral loads (Watts et al, 2007). Building cores can be arranged in several ways. Central cores integrating with the outer structure resist lateral loads more effectively and open up the perimeter for light and view, enabling efficient workplaces. Buildings with side cores have the advantage of homogeneous workplaces, which is usually organized into one space. This building type is very attractive to users without cellular offices and has until recently been the standard in Japan and Korea (Kohn and Katz, 2002). Multiple cores are common in low-rise buildings, which have very large or narrow floor slabs.

The design of the core significantly affects the overall space efficiency of the buildings, vertical circulation, and distribution of mechanical and electrical shafts. The lifting strategy drives the core size and has a major impact in terms of design on all high-rise office buildings. One of the drivers is the acceptable period of time for users to get from ground floor to their destination. The ideal solution balances a number of factors such as the number and the speed of lifts, group sizes, building zones and the core arrangement, considering the space usage as well as cost (Watts, et al, 2007). In order to achieve the maximum space efficiency of a high-rise office building, the core must be reduced to an acceptable ratio of the gross floor area, while coping with the fire regulations and achieving an effective vertical transportation with the elevators.

In many high-rise office buildings structural elements within and around the core interact with the perimeter frame. These structural elements can be constructed with either steel or reinforced concrete, or both. In the case of a reinforced concrete core, its structural weight can be very heavy, thus inducing an additional cost for the foundation. In United States, steel is commonly used as the structural material and lightweight fire-rated drywall is used to form the walls in order to reduce its thickness and save the foundation cost and construction time (Ho, 2007). However, in Asian countries, the use of the structural steel with drywall forming is less common because their costs are higher than the conventional reinforced concrete construction. High-strength concrete is generally used to reduce the thickness of reinforced concrete core wall enabling more efficient spaces.

As the ten tallest office buildings of the world and Turkey are investigated, it is found that single and central cores are common. Only the Bank of China has a split core with decreasing dimension as it rises. Reducing the number of elevators enables more efficient work places in high-rise office buildings. The core-to-gross floor area ratios change between 22 % and 30 %, with an average ratio of 26 % (**Table 5**). For seven of the ten tallest buildings of the world, the plan shapes of the cores do not match with the floor slab, thus differentiating leasing depths on each side of the buildings. Nine of the Turkey's tallest office buildings have single and central cores, except for the Garanti Bank Headquarters with a split core located outside the perimeter of the floor slab. This approach enables to organize the rest of the floor slab into one workplace. The core-to-gross floor ratios have a wide range between 19 % and 32 % as seen from **Table 5**, having an average value of 30 %. For five of the selected ten examples, core shapes match with the floor slabs and leasing depths are the same on each side of the buildings.

	Name of Building	Number of cores	Location of core		Core integrity		Core Area (m^2)	Core/ GFA (%)
			Center	Outside	Yes	No		
WORLD	Taipei 101 Tower	Single	X			X	665	25
	Shanghai WFC	Single	X		X		750	30
	Petronas T. 1-2	Single	X			X	530	25
	Sears Tower	Single	X			X	1113	22
	Jin Mao Tower	Single	X			X	800	29
	Two International Finance Center	Single	X		X		740	26
	CITIC Plaza	Single	X			X	480	22
	Shun Hing Square	Single	X			X	570	26
	Central Plaza	Single	X		X		560	25
	Bank of China	Double	X			X	800	30
TURKEY	İşbank Tower 1	Single	X			X	450	32
	Mertim	Single	X		X		240	19
	Tekstilkent P. 1-2	Single	X		X		280	20
	Sabancı Center 1	Single	X			X**	225	32
	Süzer Plaza	Single	X		X		362	26
	Tat Tower 1-2	Single	X		X		318	32
	Metrocity Tower 1	Single	X*		X		262	32
	Sabancı Center 2	Single	X			X**	225	31
	Beybi Giz Plaza	Single	X		X		200	25
	Garanti Bank Headquarters	Single		X			300	20

Table 5. Core configuration and the core-to-gross floor area in sample buildings from the world and Turkey.

*The building has an eccentric core.

** The buildings have cores with unique plan forms.

Structural System

For contemporary high-rise office buildings, it is important to adopt a structural system to cope with an open-plan, in which all office workers perform in a common space. Several structural solutions have been developed and are combined to meet the architectural requirements, such as column-free spaces and maximum leasing depth allowed by the site regulations. In 1969 Fazlur Khan classified structural systems for high-rise buildings according to their height (Khan, 1969). Later, he upgraded these diagrams (Khan, 1972, 1973), and developed schemes for both steel and concrete (Ali, 2001; Ali and Armstrong, 1995; Schueller, 1986; Iyengar, 1986). According to a recent literature review by Ali and Moon (2007), structural systems for high-rise buildings are divided into two broad categories, which are interior and exterior structures. This classification is based on the distribution of the components of the primary lateral load-resisting system over the building. A system is categorized as an interior structure, when the major part of the lateral load resisting system is located within the interior of the building. Likewise, if the major part of the lateral load resisting system is located at the building perimeter, this system is categorized as an exterior structure. The authors also state that, any interior structure is likely to have some minor components of the lateral load-resisting system at the building perimeter, and any exterior structure may have some minor components within the interior of the building.

The two basic types of interior structures are the moment-resisting frames and shear trusses/walls. These systems are usually arranged as planar assemblies in two principal orthogonal directions and may be employed together as a combined system in which they interact. Another important system in this category is the core-supported outrigger structure, which is very widely used for super high-rise buildings (Ali and Moon, 2007). Unlike the interior structures, such as moment-resisting frames or shear walls are concentrated in a zone like the core, it is inevitable to achieve the maximum space efficiency.

In the exterior structures category, tubular systems, which can be defined as a three-dimensional structural system utilizing the entire perimeter to resist lateral loads, are the most typical. The early application of tubular concept is attributed to Fazlur Khan in 1961 (Ali, 2001). Widely spaced framed tube, braced tube, tube-in-tube and bundled tube are the sub-categories of this structural system (Taranath, 1998). Since the tubular wall at the perimeter of the tower resist the entire lateral load, the interior floor slab is kept relatively free of core bracing and large columns, thus increasing the net leasable area of the building.

A recent type of the exterior structures is the diagrid system, which is a varied version of tubular structures. Diagrid structures, with their structural efficiency, are also effective in providing an aesthetic character to the building.

Other types of exterior structures include space trusses, super frames and exoskeletons (Ali and Moon, 2007). These systems are effective in resisting to both lateral and gravity loads, thus enabling the maximum space efficiency for office workers, as in the case of Bank of China.

As stated in **Table 6a**, the Taipei 101 Tower, Shanghai World Financial Center, Jin Mao Tower and 2 International Finance Center are supported with composite mega-frames comprising columns of gigantic size, and shear cores located in the center. The 110-storey Sears Tower is supported by a steel bundled tube structure comprising nine modular tubes. Both the CITIC Plaza and Central Plaza utilize high-strength reinforced concrete peripheral tubes interconnected with the shear core by floor beams and slabs, thus representing a tube-in-tube structure. Petronas Tower 1 and 2, and Shun Hing Square are supported with peripheral rigid frames, linked to the central core of reinforced concrete shear walls by steel outriggers. Bank of China represents a specific structure of cross-braced space steel truss, which resists both lateral and gravity loads. The structural systems of five towers are composite, whereas the four towers utilize high-strength concrete, and one tower utilizes structural steel. Steel outrigger trusses are designed in all of the examples to combine the exterior structure with the cores, except for the Central Plaza, Sears Tower and CITIC Plaza, and each building utilizes composite floor systems comprising beams and girders, except for the Central Plaza with reinforced concrete floor system. For the eight of the ten tallest buildings of the world, the structural systems enable space efficiency and workplace flexibility by column-free floor slabs, except for the Central Plaza, with the single column in the workspace. Sears Tower has interior planning limitations due to the bundled tube configuration and Central Plaza has the same problem with the single column located in the workplace.

In Turkey, the two tallest buildings, İş Bank Tower and Mertim are supported by tube-in-tube structures, comprising closely spaced columns combined with flat floor edge beams, and a central core of shear walls (**Table 6b**). The other examples utilize an outer rigid frame consisting of widely spaced columns, shear walls and central cores of shear walls, except for the Garanti Bank Headquarters, which utilize a conventional rigid

	Name of Building	Number of floors	Structural Material	Definition of the Structural System
WORLD	Taipei 101 Tower	101	Composite	The building is supported by a mega-frame, which comprises eight mega-columns of size 2.4 m x 3.0 m. These columns are boxes of 80 mm thick steel slabs filled with high-strength silica fume concrete up to the 62nd floor. A multi-cellular core of braced steel, becoming massive reinforced concrete shear walls below the 7th floor, is coupled to the fin columns with mega-truss outriggers at every eight floor. Within these box-like cells, secondary frames support office decks of lightweight concrete on metal decking (Wells, 2005).
	Shanghai World Financial Center	101	Composite	The building is supported by three parallel and interacting structures: (1) A Vierendeel moment-resisting space frame, consisting of fin columns, diagonals and the belt truss; (2) Concrete core walls; (3) Outrigger trusses interacting between the core walls and the mega columns of the space frame (Robertson and See, 2007).
	Petronas Tower 1-2	88	Composite	The structural system comprises a mega-frame of high-strength concrete columns and beams interacting with a high-strength concrete shear core. The perimeter columns of 2.4 m diameter and core walls are connected with composite girders and two-story high steel outrigger trusses at four levels. Typical floors consist of wide flange beams spanning from the core to the ring beams with a composite metal deck and concrete topping (Pelli and Crosbie, 2001; Taranath, 1998; Zacnik, et al, 1998; Mohamad, et al, 1995).
	Sears Tower	114	Steel	The building is supported by a bundled-tube system comprising of nine individual tubes of 22.9 m x 22.9 m. As the tower climbs upward, the tubes drop off at the 50th, 66th and 90th floors. The columns of each tube are spaced at 4.6 m. The structure also has diagonal bracing only on the mechanical levels before each setback. The structural floor system comprises composite wide flange beams with a 7.6 cm composite metal deck with 6.3 cm light-weight concrete topping floor slab (Taranath, 1998; Zacnik, et al, 1998, Thornton, et al, 1996).
	Jin Mao Tower	88	Composite	The structural system comprises a reinforced concrete core and eight perimeter mega-columns of 1.5 m x 4.88 m, which are encased in high-strength concrete and linked by steel outrigger trusses at three levels and capped with a three-dimensional steel space frame at the top level. The structural floor system comprises composite wide flange beams with a 7.6 cm composite metal deck with 8.25 cm concrete topping floor slab (Taranath, 1998; Zacnik, et al, 1998; Thornton, et al, 1996).

Table 6a. The structural system definition of the sample buildings from the world.

	Name of Building	Number of floors	Structural Material	Definition of the Structural System
WORLD	Two International Finance Center	88	Composite	The building is supported by a large high-strength reinforced concrete core and eight perimeter composite mega-columns, which are encased in high-strength concrete and linked to the core by story-height steel outrigger trusses at four levels (Binder, 2006).
	CITIC Plaza	80	R. Concrete	The structural system is a tube-in-tube structure comprising twenty high-strength reinforced concrete perimeter columns, spandrel beams and a reinforced concrete central core. The inner and outer tube is linked with the floor beams and slabs (Binder, 2001; 2006).
	Shun Hing Square	69	Composite	The building is supported by a peripheral rigid steel frame and reinforced concrete central core, which is linked to the outer frame by rigid steel outriggers at four levels. Structural floor system comprises closely spaced steel beams and one-way spanning slabs (Wells, 2005).
	Central Plaza	78	R. Concrete	The building is supported by a high-strength concrete tube-in-tube system comprising perimeter columns at 4.6 m on centers and spandrel beams 1.1 m deep. The triangular-shaped core concentrates the reinforced concrete shear walls carrying approximately 10 % of the total wind shear. The structural floors are conventional with primary and secondary beams carrying metal decking with 16 cm thick reinforced concrete slab (Beedle and Rice, 1995).
	Bank of China	70	Composite	The structural system is a cross-braced space truss comprising four concrete encased steel mega-columns at building corners with a size of 4.3 m x 7.93 m, and single column at the center above 25th floor. This structural scheme supports lateral loads as well as the entire weight of the building. The structural floor comprises steel beams spanning between composite core walls and exterior frame carrying the steel slabs and 12 cm concrete topping (Taranath, 1998; Ali and Armstrong, 1995).

Table 6a (continued). The structural system definition of the sample buildings from the world.

frame for the workplace and a shear core at one side of the floor slab (see **Table 1b**). This conventional frame prevents the design of column-free spaces and flexibility of the floor slab. Also for the two Sabancı Towers, Süzer Plaza and Metrocity 1, the columns of the peripheral frames are recessed, thus reducing the flexibility of space and leaving a space between the columns and exterior wall (see **Figure 1b**).

DISCUSSION AND CONCLUSIONS

As properly-planned high-rise office buildings are discussed, space efficiency, which is one of the efficiencies like structural, constructional, energy and operational, emerges as a major concern to be focused on. However, when the aim is to increase the rental income, space efficiency becomes significant in comparison with other efficiencies. In this context, this research presents important parameters for the design of high-rise office buildings and their relationship with space efficiency. Efforts have been made to present visual analysis, which explains the significance of space efficiency and the relationships of parameters that impact this issue.

	Name of Building	Number of floors	Structural Material	Definition of the Structural System
TURKEY	İş Bank Tower	52	R. Concrete	The building is supported by a tube-in-tube structure. The perimeter tube comprises columns, which are spaced 3.5 m on centers and have size of 0.6 m x 0.9 m and, and floor edge beams of 0.35 m height. The inner core consists of shear walls with 0.6 m width. The structural floor system linking the inner core to the perimeter tube is a reinforced concrete waffle slab with a structural height of 0.35 m (Balioğlu, 1999; Tekeli and Sisa, 1994).
	Mertim	49	R. Concrete	The structural system is a tube-in-tube, with the perimeter tube comprising columns of 1.45 m x 0.7 m size and located 1.775 m on centers, and spandrel beams of 1.475 m x 0.45 m size. The core consists of shear walls with a thickness of 0.5 m at the lower floors. Reinforced concrete floor beams, which link the perimeter tube and the central core, have a size of 0.70 x 0.45 m and are located 3.55 m on centers with a slab of 12 cm thickness (Çili and Karataş, 1992).
	Tekstilkent Plaza 1-2	44	R. Concrete	The towers are supported by shear walls at the perimeter, widely spaced columns recessed from the perimeter and a central shear core. The interaction between the outer system and the core is provided by the waffle slab.
	Sabancı Center 1	39	R. Concrete	The structural system comprises an outer rigid frame with widely spaced columns on the two sides of the central shear core. The frames consist of four columns of 0.7 m x 1.20 m size and one 0.7 m x 1.5 m size, and band beams connecting the columns to each other and to the shear walls on the edges of the floor slabs. The interaction between the outer frame, shear walls and the shear core is provided by a 20 cm floor slab (Uysaler, 1995).
	Süzer Plaza	34	R. Concrete	The structural system comprises an outer rigid frame with 8.4 m spaced columns, and a reinforced concrete central core of shear walls. The sizes of these columns are 1.5 m x 1.5 m at the lower floors, and are linked by band beams to each other as well as to the core walls. On the corners of the reinforced concrete frame, hollow columns of 2.6 m diameter are placed. The floor system comprises primary band beams spanning the distance between the shear core and the exterior frame, waffle slab on the corners, and one-way concrete ribbed slabs between the corners. The floor cantilevers 2.0 m out of the frame on all sides of the tower by one way joists (Alarçin, 1991; Özgen and Sev, 2000).

Table 6b. The structural system definition of the sample buildings in Turkey.

	Name of Building	Number of floors	Structural Material	Definition of the Structural System
TURKEY	Tat Tower 1-2	34	R. Concrete	The structural system comprises an outer rigid frame with widely spaced columns and a central shear core. The reinforced concrete frame consists of twelve columns of 1.45 m x 1.20 m and 1.40 m x 1.20 m sizes, which are linked with floor edge beams of 0.4 m x 1.0 m size. The shear core, comprising outer walls of 0.5 m width and inner walls of 0.4 m width, is the primary element to resist the lateral loads. The outer frame is linked to the shear core by the flat slab of 0.30 m height (Özgen and Sev, 2000).
	Sabancı Center 2	30	R. Concrete	As the same with Sabancı Center 1.
	Beybi Giz Plaza	34	R. Concrete	The structural system comprises two peripheral rigid frames placed on the two sides of a shear core. The peripheral rigid frames on each wing consist of columns, which are spaced 3.1 m on the centers, and one column is located on the center of the floor slab with a size of 1.4 m x 1.2 m. The corner columns of the frame are 0.6 m x 0. 6 m, whereas the others are 0.7 m x 0.7 m. The outer columns and the single column are linked with flat beams, whereas the interaction between the rigid frame and the shear core is provided by a 0.4 m thick waffle slab, consisting of 1.0 m spaced joists.
	Garanti Bank Headquarters	22	R. Concrete	The building is supported by a reinforced concrete rigid frame, a shear core located outside the floor slab and two perforated shear walls at the two sides of the curvilinear floor slab. The columns throughout the floor slab are linked by curvilinear flat beams and the thickness of the floor slab is 0.20 m.

Table 6b (continued). The structural system definition of the sample buildings in Turkey.

The following are the major conclusions of the research:

• Structural system and core configuration are the most important factors affecting the space efficiency of high-rise office buildings, as they are closely related with the shape of the floor slab, leasing depth, floor height and vertical transportation. Cores in high-rise office buildings are much more complex than in conventional buildings, and their design is fundamental to the development and the operational effectiveness of a tower. Key elements of the core are the structural elements and elevators while the lifting design is the major determinant of the core size and the space efficiency, and it determines the occupant travel and maximum waiting times. By the input of a specialist, dividing a building into a number of zones, each served by an appropriate sized group of lifts to decrease the core size, will increase the space efficiency. The use of sophisticated controls for elevators is also an effective way of minimizing the number of elevators and waiting periods.

As analyzed in the selected examples, space efficiency of the towers abroad are acceptable; however, most of the Turkish examples are less space efficient. The average space efficiency of two sample groups are similar, even though the number of storeys and floor slabs of Turkish examples are almost the half the examples abroad, which originates from larger core areas and larger dimensions of vertical structural elements.

• Depending on requirements of the clients or the tenants, areas of the core elements can vary significantly, affecting the space efficiency. However, even though floor slab areas and heights of Turkish examples are almost half the examples abroad, the average ratio of core-to-gross floor area for Turkish examples is higher, thus decreasing the area of workplace and space efficiency. The vertical transportation elements, such as elevators and fire stairs require more analysis for more economic and efficient solutions of the floor plans in conjunction with the construction of high-rise office buildings in Turkey.

• Central core approach is commonly used in the world and in Turkey for high-rise office buildings. The cores are interconnected with the main structural frame, thus resisting a substantial amount of the lateral loads in all examples, without exception. This interconnection between the core and the structural frame is provided by the structural floor system and steel outrigger trusses in sample buildings at abroad, whereas examples from Turkey do not utilize any steel outrigger trusses. Utilization of steel outrigger trusses must be supported by designers and contractors of high-rise office developments to improve the efficiency of structural system, thus affecting the size of the structural members.

• The two common structural systems for the tallest office buildings of the world are composite mega-columns and central core with outriggers, and reinforced concrete tube-in-tube without outriggers system. Either steel or concrete structures are used; however, high-strength concrete is more common due to its lower cost, compared with steel. In Turkey, the most common structural system for the ten tallest office buildings is reinforced concrete perimeter frame with central core and tube-in-tube. High-strength concrete is not widely used in Turkey due to its higher cost and production conditions, consequently increasing the size of the vertical structural members. Use of high-strength concrete for columns and shear walls must be supported by designers, practitioners, contractors and also must be subsidized by the government in Turkey.

• Space efficiency could be higher, if buildings in Turkey utilize state-of-the-art structural systems and materials, as well as elements of the vertical transportation, to have smaller vertical structural elements and smaller core areas.

High-rise office buildings pose different questions for those that design, build, own and operate them. For each of these stakeholders, there is an inherent motivation for profit, generally led by responsibility for shareholders. Developing high-rise office buildings to obtain this profit demands acceptance of higher risks from the outset. To minimize these risks, increasing space efficiency is of vital importance. Space efficiency is only a number of resulting from an inter-related decision making parameters during the early planning and development of the high-rise office buildings. Efficiency of net-to-gross floor area is the key to balance construction costs and total rental values. When material choice and issues of efficiency of structure and services are integrated to assess the various options, more space-efficient solutions can be reached.

REFERENCES

ABU-GHAZALAH, S. (2007) Skyscrapers as Tools of Economic Reform and Elements of Urban Skyline: Case of the Abdali Development Project at Amman, *METU Journal of the Faculty of Architecture*, (24:1) 49-70.

ALARÇİN, M. (1991) *High-Rise Building Projects Between 1985-1990 in Turkey*, unpublished Master Thesis, İstanbul Technical University, İstanbul.

ALI, M.M. (2001) *Art of the Skyscraper: The Genius of Fazlur Khan*, Rizzoli, New York.

ALI, M. M., ARMSTRONG P. J. (1995) *Architecture of Tall Buildings*, Council on Tall Buildings and Urban Habitat Committee 30, McGraw-Hill, Inc., New York.

ALI M.M., MOON, K.S. (2007) Structural Developments in Tall Buildings: Current Trends and Future Prospects, *Architectural Science Review*, (50.3) 205-23.

ARNOLD, C. (1980) In Earthquakes, Failure Can Follow Form, *AIA Journal*, (June) 33-41.

BALIOGLU, I. (1999) The Structural System Project of Is Bank General Headquarters Complex (in Turkish), *Design Construction*, (160) 74-76.

BAUM, A.E. (1994) Quality and Property Performance, *Journal of Property Valuation & Investment*, (12:1) 31-46.

BEEDLE, L. S., RICE, D. B. (Eds.) 1995 *Structural Systems for Tall Buildings*, Council on Tall Buildings and Urban Habitat Committee 3, McGraw-Hill Inc., New York.

BINDER, G. (Ed.) (2001*) Tall Buildings of Asia and Australia*, Images Publishing, Hong Kong.

BINDER, G., (Ed.) (2006) *101 of the World's Tallest Buildings*, Images Publishing Dist A/C, Hong Kong.

CLARK, W.C., KINGSTON, J.L. (1930) *The skyscraper. A study in the economic height of modern office buildings,* American Institute of Steel Construction, New York/Cleveland.

CRONE, G. J. (1990) The Humanization of Tall Buildings, *Council on Tall Buildings and Urban Design*, *eds*. L. S. Beedle, D. B. Rice, Council on Tall Buildings and Urban Habitat, Van Nostrand Reinhold Company, New York;185-197.

CTBUH, (2008) *100 Tallest Buildings of the World*, Council on Tall Buildings of the World, (http://www.ctbuh.org/Portals/0/Tallest/CTBUH_Tallest100.pdf, accessed November, 2008).

ÇİLİ, F., KARATAŞ, H. (1992) The Assessment of the Structural System of Mersin Metropolis Building, *2nd National Symposium on Tall Buildings*, İstanbul Technical University, Faculty of Architecture, 4-6 November 1992, 280-9.

DAVIS L., EVEREST, (1997) *High-Rise Office Towers - Cost Model, May 1997*, (http://www.building.co.uk/story.asp?storyCode=1025316, accessed November 2008).

Emporis.com (2008)(http://www.emporis.com/en/wm/ci/bu/sk/li/?id=100460&bt=9&ht=2&sro=0, accessed November 2008).

HO, D.C.W. (1999) Preferences on Office Quality Attributes, *International Real Estate Conference*, 26-31 January 1999, Kuala Lumpur, (http://www.prres.net/papers/Ho_Preferences_On_Office_Quality_Attributes.pdf, accessed November 2008).

HO, P.H.K. (2007) Economics Planning of Super Tall Buildings in Asia Pacific Cities, *Strategic Integration of Surveying Services*, FIG Working Week, Hong Kong SAR, China, 13-17 May 2007; 15-30.

IYENGAR, H. (1986) Structural and Steel Systems, *Techniques and Aesthetics in the Design of Tall Buildings*, Bethlehem, PA, Institute for the Study of High-Rise and Habitat, Lehigh University; 57-69.

KHAN, F.R. (1969) Recent structural systems in steel for high-rise buildings, *Proceedings of the British Constructional Steelwork Association Conference on Steel in Architecture*, British Constructional Steelwork Association, London; 67-78.

KHAN, F.R. (1972) Influence of design criteria on selection of structural systems for tall buildings, *Proceedings of the Canadian Structural Engineering Conference*, Toronto, Canadian Steel Industries Construction Council; 1-15.

KHAN, F.R. (1973) Evolution of structural systems for high-rise buildings in steel and concrete, *Tall Buildings in the Middle East and East Europe: Proceedings of the 10th Regional Conference on Tall Buildings-Planning, Design and Construction*, Czechoslovak Scientific and Technical Association, Bratislava; 75-92.

KIM, H, ELNIMEIRI, M. (2004) Space Efficiency in Multi-Use Tall Building, *Tall Buildings in Historical Cities - Culture and Technology for Sustainable Cities*, October 10-13, Seoul, 748-55.

KLABER, E.H. (1930) The Skyscraper: boon or bane?, *Journal of land and Public Utility Economics*, 6(4) 354-358.

KOHN, A. E., KATZ, J. (2002) *Building Type Basics for Office Buildings*, S. A. Kliment, ed., John Wiley and Sons, New York.

KOZAK, J. (1991) *Steel-Concrete Structures for Multi-storey Buildings*, Elsevier, Amsterdam.

MCNEILL, D., TEWDWR-JONES, M. (2003) Architecture, Banal Regionalism and Re-territorialism, *International Journal of Urban and Regional Research*, (27:3) 738-43.

MOHAMAD, H., CHOON, T., AZAM, T., TONG, S. (1995) The Petronas Towers- The Tallest Building in the World, *Habitat and the High-Rise. Tradition and Innovation, Fifth World Congress*, Council on Tall Buildings and Urban Habitat, Amsterdam, May 14-19, 321-57.

NEWMAN, P., THORNELY, A. (2005) *Planning World Cities: Globalization and Urban Politics*, Palgrave MacMillan, Basingstoke.

ÖZGEN, A, SEV, A. (2000) *The Structural Systems for Multi-Storey High-Rise Buildings* (in Turkish), Birsen Yayınları, İstanbul.

PELLI, C., CROSBIE, M.J. (2001) *Petronas Twin Towers: The Architecture of High Construction*, John Wiley and Sons Ltd., New York.

ROBERTSON, L. E., SEE, S.T. (2007) *The Shanghai World Financial Center* (http://www.structuremag.org/Archives/2007-6/SF-Shanghai-Robertson-June07.pdf, November 2008).

SCHUELLER, W. (1986) *High-rise Building Structure*, 2nd Edition, Krieger, Malabar.

SEV, A. (2001) *Analysis of Tall Buildings in Turkey and at Abroad from the Architectural and Structural Point of Views* (in Turkish). PhD Thesis, Mimar Sinan University, Institute of Science and Technology, İstanbul.

SkyscraperPage.com (2008) (http://skyscraper.com, accessed November 2008).

SRELITZ, Z., (2005) *Tall Buildings: A Strategic Design Guide*, The British Council for Offices and RIBA Publishing, London.

TARANATH, B.S. (1998) *Steel, Concrete and Composite Design of Tall Buildings*, McGraw-Hill, Inc., New York.

TEKELİ, D., SİSA, S. (1994) *Projects: Buildings 1954-1994*, (in Turkish), YEM, İstanbul.

THORNTON, C.H., HUNGPRUKE, U., JOSEPH, L.M. (1996) Composite High-Rise Construction in Asia, *Tall Buildings - A World Review*, eds. L.S. Beedle, D.B. Rice, Council on Tall Buildings and Urban Habitat, Pennsylvania; 331-8.

UYSALER, D. (1995) Sabancı Center, *International Symposium on Recent Trends in Building Construction*, Mimar Sinan University, İstanbul, 3-5 May 1995, 133-48.

WATTS, S., KALITA, N., MACLEAN, M. (2007) The Economics of Super-Tall Towers, *The Structural Design of Tall and Special Buildings*, (16) 457-70.

WELLS, M. (2005) *Skyscrapers, Structure and Design*, Yale University Press, New Haven.

YEANG, K. (1995) *The Skyscraper, Bioclimatically Considered*, Academy Editions, London.

YEANG, K. (2000) *Service Cores: Detail in Building*, John Wiley and Sons, London.

ZACNIK, I., SMITH, M., RICE, D. B. (1998) *100 of the World's Tallest Buildings*, Council on Tall Buildings and Urban Habitat, Gingko Press, Hong Kong.

Alındı: 19.11.2008, **Son Metin:** 30.07.2009

Anahtar Sözcükler: yüksek ofis binası; kullanım alanı etkinliği; kat planı; taşıyıcı döşeme; brüt kat alanı; net kat alanı; taşıyıcı sistem; çekirdek planlaması.

YÜKSEK OFİS YAPILARINDA KULLANIM ALANI ETKİNLİĞİ

Yüksek ofis binalarında çalışma alanına olan talep ekonomik, sosyal ve politik faktörlere bağlı olarak değişkenlik göstermekte, dolayısıyla ülkeden ülkeye ofis yapılarının kullanım alanı etkinliğinde önemli farklılıklar olabilmektedir. Bu çalışmanın amacı dünyada ve Türkiye'de yapılan yüksek ofis binalarını, kullanım alanı etkinliğini etkileyen faktörler açısından inceleyerek, benzerlik ve farklılıkları ortaya koymaktır. Bu doğrultuda dünyanın ve Türkiye'nin, yapımı tamamlanmış olan en yüksek on ofis binası seçilerek, bu binalar kat adedi, bina yüksekliği, brüt kat alanı, net kat alanı, çekirdek büyüklüğü ve geometrisi, cephe ve çekirdek

arasındaki uzaklık, kat ve temiz kat yüksekliği, taşıyıcı sistem ve çekirdek-taşıyıcı sistem etkileşimi açısından karşılaştırılmıştır. Yapılan inceleme sonucunda, yükseklikle arasında önemli düzeyde farklılıklar olmasına karşılık, ortalama kat alanı etkinliğinin dünyadaki ve Türkiye'deki örneklerde yakın değerlerde olduğu görülmüştür. Türkiye'deki örneklerin yabancı örneklerin yaklaşık yarısı kadar yüksekliğe ve kat adedine sahip olduğu dikkate alınırsa, kullanım alanı etkinliğinin yurt dışındaki örneklere yakın olması dikkat çekicidir. Bu durum çekirdek alanlarının ve düşey taşıyıcı eleman boyutlarının, dünyadaki örneklere oranla daha büyük tasarlanmasından kaynaklanmaktadır. Türkiye'de yüksek dayanımlı beton kullanımının yaygınlaşmaması, ana strüktürel çerçeve ile çekirdek arasında etkileşimi sağlayarak, strüktürel eleman boyutlarını azaltan yatay kafes kirişlerin kullanılmaması, asansörlerde bölgelendirme, göklobi, çift katlı kabin ve akıllı sistemler gibi tasarım stratejilerinin uygulanmaması, Türkiye'deki yüksek ofis binalarında kat alanı etkinliğinin daha düşük seviyelerde kalmasına neden olan başlıca nedenlerdir. Ülkemizdeki yüksek yapı uygulamalarında dünyadaki son gelişmelerin daha yakından takip edilmesi gerekmektedir.